REMARKS

In the Office action mailed on August 8, 2006, the Examiner objected to the Specification and rejected claims 1-3 under at least one of 35 U.S.C. § 112, paragraph 1; 35 U.S.C. § 112, paragraph 2; and 35 U.S.C.§ 103(a). In addition claim 3 was objected to under 37 CFR 1.75 as being a substantial duplicate of claim 2.

By means of the present Amendment, the Specification and claim 1 have been amended and claims 2 and 3 have been cancelled. Applicant submits that no new matter has been introduced in the present Amendment. Support for these amendments may be found, for example, in the originally-filed claim 2, the Abstract, and pages 3 and 4 of the Specification.

In view of the amendments to the Claims and Specification, together with the following remarks, Applicant respectfully requests reconsideration and withdrawal of all grounds of rejection and objection.

Objection to the Specification

The Examiner objected to the Abstract of the Specification for including the phrases "The invention relates to" and "Fig. 3 is intended for the abstract." To address the Examiner's objection, both phrases have been removed in the present Amendment. Thus, Applicant respectfully requests that the Examiner withdraw these objections to the Abstract.

In addition, the Specification was objected to under 37 CFR 1.71 as not clearly describing the term "electrical shaft." Specifically, the Examiner did not understand what was meant by an electrical shaft and how the electrical shaft drives the rollers with the same torque on both sides as described on page 5 of the Specification.

Applicant respectfully submits that the term "electrical shaft" is a common technical term known to those of ordinary skill in the art. Applicant submits that an electrical shaft is a term for a specific electrical coupling of two electrical engines that results in the rotation of the rollers (1,2) at the same speed. Applicant encloses a copy of a page of the technical encyclopedia "Lueger," which defines the German phrase elektrische Welle –"electrical shaft" together with an English translation for the Examiner's consideration. In addition, Applicant encloses a copy of a 2000 IEEE publication entitled *A Static "Quasi Electric Shaft" for n Similar Rotor Winding Induction Motors* authored by Ricardo Fuentes.

As electrical shaft is a known term, which defines the connection of the drives so as to synchronize the drives to rotate at the same speed, Applicant believes that the Specification adequately and clearly describes the claimed subject matter and requests that this objection to the Specification be withdrawn.

Rejection of Claims 2-3 Under 35 U.S.C. §112, First Paragraph

Claims 2 and 3 were rejected under 35 U.S.C. §112, first paragraph as failing to comply with the enablement requirement for allegedly failing to describe what is meant by the term "electrical shaft." Applicant respectfully submits that the term "electrical shaft" is a term that is commonly known in the art. Applicant directs the Examiner to the enclosed definition as published by the Lueger technical encyclopedia and the enclosed IEEE publication. As the term electrical shaft is commonly known, Applicant respectful submits that the term electrical shaft is properly enabled in claims 2 and 3 (and now in amended claim 1), especially in light of the description on page 5 of Applicants specification together with Figure 1 illustrating the electrical shaft W in combination with drives 18a, 18b, 22a, and 22b. Thus, Applicant respectfully requests that the 35 U.S.C. §112, first paragraph be reconsidered and withdrawn.

Rejection of Claims 1-3 Under 35 U.S.C. §112, Second Paragraph

Claims 1-3 were rejected under 35 U.S.C. §112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which Applicant regards as the invention.

Specifically, independent claim 1 was rejected for including the limitation "one roller" as it is not clear whether the "one roller" refers to one of the rollers claimed in line 2 of Applicant's claim 1 or a different roller. To address this deficiency, Applicant has amended claim 1, as suggest by the Examiner to recite "one of said rollers."

Claims 2 and 3 were rejected for including the limitation "each roller" and "all rollers." As claims 2 and 3 are cancelled in the present Amendment, these rejections are now moot.

Applicant believes that the amendments to claim 1 and the cancellation of claims 2 and 3 address and cure all 35 U.S.C. §112, second paragraph deficiencies. Accordingly, Applicant

respectfully requests reconsideration and withdrawal of all 35 U.S.C. §112, second paragraph rejections.

Double Patenting Objection

Claim 3 was objected to under 37 CFR 1.75 as being a substantial duplicate of claim 2. In response, Applicant has cancelled claim 3 and thus requests that the double patenting objection be withdrawn.

Rejection of Claim 1 Under 35 U.S.C. § 103(a)

Independent claim 1 stands rejected under 35 U.S.C. § 103(a) as being unpatentable in view of the combination of U.S. Patent No. 5,744,006 to Mausser et al. (hereinafter "Mausser") and U.S. Patent No. 4,905,910 to Wuestner (hereinafter "Wuestner"). To establish a *prima facie* case of obviousness, three basic criteria must be met. First, there must be some suggestion or motivation to modify the references or to combine the reference teachings. Second, there must be a reasonable expectation of success. Finally, the prior art references must teach or suggest all of the claim limitations. M.P.E.P. 706.02(j). In the present case, the cited prior art references fails to support a *prima facie* case of obviousness because the references fail to teach or suggest all of the elements of Applicant's independent claim 1. Specifically, both Mausser and Wuestner fail to teach or suggest Applicant's claimed compacting press including two counterrotating rollers, with said rollers at each of their two sides comprising their own electric motor drives and electric motors, wherein the electric motors of the drives of each of said rollers are interconnected to each other by an electrical shaft so that the rollers rotate at the same speed.

Mausser discloses an apparatus for dewatering mixtures that includes two pressure elements (e.g., rollers 2, 3). See, Abstract of Mausser. As the Examiner points out on page 6 of the Office Action, Mausser fails to teach or suggest that the rollers 2,3 include their own electric motor drives. Rather, it appears that only roller 3 includes an electric motor 24. Thus, Mausser fails to teach or suggest that the "electric motors of the drives of each of said rollers are interconnected to each other by an electrical shaft so that the rollers rotate at the same speed," at least because Mausser fails to teach or suggest more than one motor drive.

Wuestner fails to cure the deficiencies of Mausser. Wuestner teaches a double roll machine including four drive motors. See, Abstract of Wuestner. However, Wuestner is silent with respect to electrically connecting the drive motors so that the rollers rotate with the same speed or with an electrical shaft. In fact, referring to the only figure of Wuestner, there is no connection between the four motor drives (19, 20, 21, and 22) of Wuestner. Thus, Applicant respectfully submits that Wuestner fails to teach or suggest Applicant's claimed compacting press including "two counterrotating rollers, with said rollers at each of their two sides comprising their own electric motor drives and electric motors, wherein the electric motors of the drives of each of said rollers are interconnected to each other by an electrical shaft so that the rollers rotate at the same speed."

Since neither Mausser nor Wuestner teaches or suggests all of the elements of Applicant's independent claim 1, Applicant respectfully submits that a *prima facie* case of obviousness does not exist. As a result, Applicant respectfully requests reconsideration and withdrawal of the 35 U.S.C. § 103(a) rejection.

CONCLUSION

In view of the foregoing, Applicant respectfully submits that the claim 1 is in condition for allowance and request favorable action. The Examiner is welcome to contact Applicant's attorney at the number below with any questions.

Respectfully submitted,

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Band 2

GRUNDLAGEN DER ELEKTROTECHNIK UND KERNTECHNIK

Herausgegeben von
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A–Z

DEUTSCHE VERLAGS-ANSTALT STUTTGART

1960

LUEGER

LEXIKON DER TECHNIK

Vierte, vollständig neu bearbeitete und erweiterte Auflage

in 17 Bänden

Herausgegeben von

ALFRED EHRHARDT UND HERMANN FRANKE

DEUTSCHE VERLAGS-ANSTALT STUTTGART

D

Eisenwasserstoff-Widerstand, s. Kaltleiter.

Eko-Schaltung, s. Oszillator.

elastische Streuung, s. Streuung.

electr. h. p., Kurzzeichen für die Einheit electrical horse-power. [6]

electr. h. p. hr., Kurzzeichen für die Einheit electrical horse-power hour. [6]

elektrische Welle, eine →Gleichlaufschaltung zwischen zwei →Induktionsmaschinen, die, mit je einer Welle gekuppelt, miteinander selbst elektrisch so verbunden sind, daß sie Drehzahlabweichungen unterdrücken und so für einen Gleichlauf der Wellen sorgen. Ihre Wirkung ist daher so, als ob beide Wellen gekuppelt wären. Die beiden elektrischen Maschinen bilden gewissermaßen eine elektrische Kupplung oder eine elektrische Zwischenwelle. [4]

Elektrisierungszahl, s. Dielektrizitätskonstante.

Elektrizitätsleitung, s. Leitung.

Elektrizitätsmenge, svw. →Ladung, elektrische.

Elektrizitätszähler sind Zähler zur Messung elektrischer Energie. Als E. werden in Gleichstromnetzen der →Gleichstrommotorzähler und evtl. der →Elektrolytzähler, in Wechselstromnetzen der →Induktionszähler und in Drehstromnetzen →Drehstromzähler benutzt. [3]

Elektrochemie, angewandte. Die Wechselwirkungen zwischen elektrischem Strom einerseits und chemischen Reaktionen andererseits, die an der Phasengrenze zwischen →Elektroden und →Elektrolyt auftreten und als →Elektrodenvorgänge beschrieben werden, sowie die elektrolytische Stromleitung sind Gegenstand der Elektrochemie. Daraus ergeben sich eine Reihe grundsätzlicher technischer Anwendungsmöglichkeiten:

die →Elektrolyse, d. h. die Ausnützung der beim Durchgang des elektrischen Stromes (Gleichstrom) durch Elektrolyte an den Elektroden auftretenden chemischen Vorgänge, zur Erzeugung von Metallniederschlägen in der →Galvanotechnik, zur elektrolytischen Herstellung und Raffination von Metallen, zur Metallbearbeitung beim →Elektropolieren, zur Erzeugung von Oxydüberzügen auf Aluminium bei der anodischen →Oxydation und zur Erzeugung bestimmter chemischer Substanzen;

die galvanischen →Elemente, d. h. die Erzeugung von elektrischem Strom aus der bei chemischen Reaktionen freiwerdenden Energie;

die meßtechnische Anwendung, z. B. in der chemischen Analyse (→Polarographie, Potentiometrie, Konduktometrie, Amperometrie u. a.) in der pH-Messung (s. Wasserstoffionenkonzentration) u. a.;

die Anwendung der →elektrokinetischen Effekte bei der Trennung von Gemischen elektrisch verschieden geladener Stoffe, insb. zur Abtrennung von Kolloiden aus Flüssigkeiten bei der Elektrophorese. [7]

Elektrode (s. a. Elektrodenvorgänge, Elektrodenpotential, Element, galvanisches, Akkumulatoren und Elektrolyse).

Unter einer E. i. a. Sinn versteht man ein elektrochemisches Zwei- oder Mehrphasensystem, bei dem zwischen den einzelnen Phasen Ionen oder Elektronen übergehen können. Meist meint man dabei das System Metall/Lösung. Die mit dem Übergang elektrischer Ladungen verbundenen chemischen Reaktionen bezeichnet man als Elektrodenreaktionen oder →Elektrodenvorgänge. Sie spielen sich an der Phasengrenze ab.

Wenn bei einer E. nur eine Elektrodenreaktion stattfindet, spricht man von einer *einfachen* E. Bei einer *mehrfachen* E. laufen mehrere Elektrodenreaktionen gleichzeitig ab. Eine E. *zweiter Art* liegt dann vor, wenn beim Übertritt des potentialbestimmten Ions von der einen Phase in die andere in beiden keine Konzentrationsänderung stattfindet. Dies ist z. B. bei der Reaktion der Bleielektrode im →Bleiakkumulator der Fall (Bildung von unlöslichem $PbSO_4$). Im Gegensatz dazu tritt bei einer Elektrode *erster Art* beim Übertritt des potentialbestimmenden Ions mindestens in einer der beiden Phasen eine Konzentrationsänderung auf.

Im engeren Sinn wird die Bezeichnung E. auf die — in der Regel aus Metallen bestehenden — häufig plattenförmigen elektronenleitenden Stromzuführungen angewandt, die in den →Elektrolyt galvanischer Zellen eintauchen, gleichgültig ob es sich dabei um Anordnungen zur Elektrolyse oder um galvanische Elemente handelt.

Da in der Elektrochemie praktisch ausschließlich mit Gleichstrom gearbeitet wird, unterscheidet man die E. verschiedener Polarität und bezeichnet sie als Anode bzw. Kathode. Im Gegensatz zu der früher üblichen Gleichsetzung von Anode und positivem Pol, sowie Kathode und negativem Pol, werden die E. heute nach der jeweiligen Richtung der Elektrodenvorgänge bzw. nach der Stromrichtung im äußeren Stromkreis bezeichnet.

Es gilt die Definition: Bei einer galvanischen Zelle ist diejenige E. die Anode, von der aus im äußeren Stromkreis Elektronen zur anderen E., zur Kathode, fließen. Die Elektrodenvorgänge an der Anode bestehen demzufolge in einer Bildung von positiv geladenen Ionen bzw. in einer Entladung von negativ geladenen Ionen, auf jeden Fall also in einer Abgabe von Elektronen an das Metall der Anode. Entsprechend bestehen die Elektrodenvorgänge an der Kathode in einer Bildung von negativ geladenen Ionen bzw. in einer Entladung von positiv geladenen Ionen, auf jeden Fall in einer Abgabe von Elektronen aus dem Metall der Kathode.

Bei einem galvanischen Element ist die Anode stets der negative, die Kathode der positive Pol. Bei einer Elektrolysezelle, beispielsweise bei einem galvanischen Bad, ist die Kathode mit dem negativen Pol der Stromquelle, die Anode mit dem positiven Pol der Stromquelle verbunden. Bei einem →Akkumulator ist die Richtung der Elektrodenvorgänge während der Ladung und Entladung umgekehrt, so ist z. B. beim Bleiakkumulator die Bleielektrode während der Entladung Anode, während der Ladung dagegen Kathode.

Als E. in Röhren bezeichnet man die verschiedenen Metallteile (Anode, Kathode, Gitter, Hilfsanode, Steuerstege usw.), die zur Zu- und Ableitung der Ströme sowie zur Steuerung der Vorgänge in der Röhre dienen.

Lit.: CITCE. Bericht über elektrochemische Nomenklatur. Z. f. Elektrochemie. Bd. 7 (1954), S. 530 — Ullmanns Enzyklopädie der technischen Chemie. 3. Aufl. München, Berlin 1955. [7]

Elektrode, bipolare, s. Elektrolyse.

Elektrode, einfache, s. Elektrode.

Elektrode, mehrfache, s. Elektrode.

Elektrode zweiter Art, s. Elektrode, Akkumulatoren und Bleiakkumulator.

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USSN 10/506,726
Attorney Docket No. 20496-455

Translation of the definition of elektrische Welle as described on page 117 of Lueger:

> A synchronising switching arrangement between two induction machines, each of which are coupled to a shaft and which are electrically connected to each other so that differences in the rotation are suppressed, and therefore serve for a synchronization of the shafts. The effect is so as if both shafts are coupled together. The two electrical machines constitute therefore essentially an electrical coupling or en electrical intermediate shaft.

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A Static "Quasi Electric Shaft" for n Similar Rotor Winding Induction Motors

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Abstract: In this paper a regenerative "static electric shaft" topology is presented. This drive is valid for any number of identical motors that have similar mechanical loads. Under this condition the drive is very stable and motors operate at very similar speeds. Under unbalanced mechanical load, speeds are different, but these differences are mitigated by the effect of a bridge controlled inverter that regenerates active power to the AC lines, as in the well known subsynchronous cascade. This means a high efficient drive. Speed can be regulated through the inverter firing angle. Some preliminary results are shown. This drive is very attractive for those variable speed cases which require a great deal of motors with similar loads, like fans in a tank house of a electrowinning copper plants.

I. CONVENTIONAL "ELECTRIC SHAFT"

The "electric shaft" is an old AC induction motor drive [1],[2],[3], it used to be employed in those cases in which rotor speed have to be identical and there is no way to solve this problem by a mechanical coupling (motors are enough well separated). This drive can be designed for rotor wound induction motors. In order to get identical speeds, induction motors I.M.1 and I.M.2 are connected as shown in Fig. 1. Under stable conditions, rotor frequencies are the same for both machines. Each stator have also the same frequency, hence speeds must be identical. This drive presents a small stability range if the mechanical loads of the machines are different.

This drive have been used for two identical induction motors (I.M). If this concept is applied to more than three machine drives, severe stability problems take place.

Some fundamentals are presented using Fig 1. The two induction machines I.M.1 and I.M.2 are use to synchronize the motor drives M1 and M2. Under stable conditions rotor frequencies at I.M.1 and I.M.2, i.e., motor slips, are identical and speeds also will be identical. Fig. 2 shows an equivalent circuit for I.M.1 and

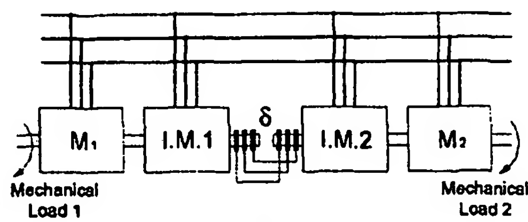

Fig 1. Compensated Electric Shaft Diagram

I.M.2 rotors connection. It order to make it simple machines are considered to be identical.

$V_{r1}=V_{r2}=V_R$: Rotor induced voltage at standstill.
$R_{r1}=R_{r2}=R_r$: Rotor resistance (per phase).
$X_{\sigma 1}=X_{\sigma 2}=X_\sigma$: Rotor leakage reactance at stator frequency
δ : Mechanical shifting between I.M. rotors (measured in electrical degrees).
I_r : Rotor current.
Z_r: Rotor impedance

The rotor current is given by:

$$\dot{I}r=\frac{\dot{V}r(1-e^{-j\delta})}{2\cdot \dot{Z}r}=\frac{\dot{V}r(1-\cos\delta+j\sin\delta)}{2\cdot\left(\frac{Rr}{s}+jX\sigma\right)} \tag{1}$$

The real current component is

$$\mathrm{Re}\{\dot{I}r\}=\frac{Vr}{2\cdot\left\{\frac{Rr^2}{s^2}+X\sigma^2\right\}}\cdot\frac{Rr}{s}\cdot(1-\cos\delta+\frac{X\sigma}{\frac{Rr}{s}}\sin\delta) \tag{2}$$

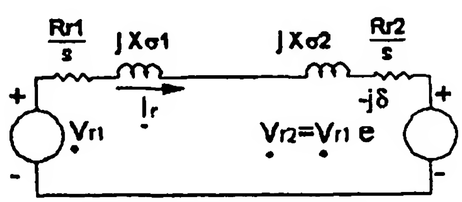

Fig. 2 Rotor Equivalent Circuit

The rotor active power can be obtained from real current component and voltage as:

$$3 \cdot Vr \cdot \mathrm{Re}\{\dot{I}r\} = \frac{3 \cdot Vr^2}{2 \cdot \left\{ \frac{Rr^2}{s^2} + X\sigma^2 \right\}} \cdot \frac{Rr}{s} \cdot (1 - \cos\delta + s \cdot \frac{X\sigma}{Rr} \sin\delta) \tag{3}$$

From active power and rotating field speed the torque can be calculated as:

$$T_1 = \frac{1}{2\pi\omega_1/p_1} \cdot \frac{3 \cdot Vr^2}{2 \cdot \left\{ \frac{Rr^2}{s^2} + X\sigma^2 \right\}} \cdot \frac{Rr}{s} \cdot (1 - \cos\delta + \frac{s}{s_{T_{max}}} \sin\delta) \tag{4}$$

The torque for a conventional induction motor is given by:

$$T_{I.M.} = \frac{3}{2\pi\omega_1/p_1} \cdot \frac{Vr^2}{\left\{ \frac{Rr^2}{s^2} + X\sigma^2 \right\}} \cdot \frac{Rr}{s} \tag{5}$$

Hence, the electric torque for I.M.1 is:

$$T_1 = \frac{T_{I.M.}}{2} \cdot (1 - \cos\delta) + \frac{T_{I.M.}}{2} \cdot \frac{s}{s_{T_{max}}} \cdot \sin\delta \tag{6}$$

For I.M.2 it can be shown that

$$T_2 = \frac{T_{I.M.}}{2} \cdot (1 - \cos\delta) - \frac{T_{I.M.}}{2} \cdot \frac{s}{s_{T_{max}}} \cdot \sin\delta \tag{7}$$

The first term corresponds to an asynchronous torque that sustains mechanical load of M.1 drive. The second term is proportional to sin δ and is a synchronizing torque that involves a power transfer between I.M.1 and I.M.2 and sustains the synchronism. It is observed that the stability limit is determined by δ = 90°(electrical degrees).

This electric shaft, shown in Fig. 1, can be simplified by eliminating machines M1 and M2 and just have induction motors I.M.1 and I.M.2 and rotor additional resistance (if rotor resistance is not connected the drive is unstable). Fig. 3 shows this simplified electric shaft configuration, which is the original drive for this paper.

It can be demonstrated [3] that the electric torque is also formed by two components: an asynchronous torque to sustain mechanical load and a synchronous component that transfer active power between I.M. in order to maintain synchronism.

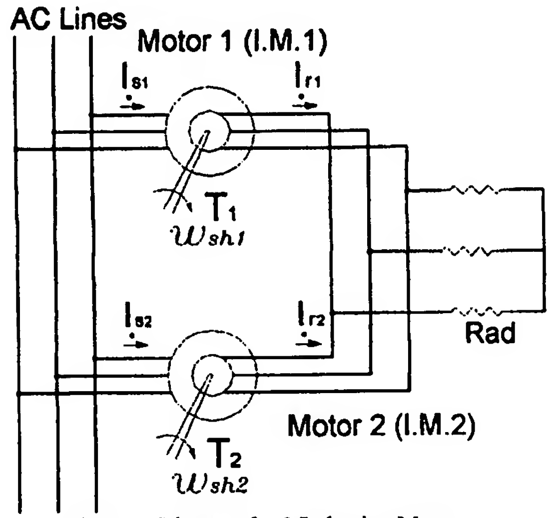

Fig 3 : Diagram for 2 Induction Motor " Simplified Electric Shaft"

The torque relationships are

$$T_1 = T_{asynch} + T_{synch} \quad \text{(I.M.1)} \tag{8}$$

$$T_2 = T_{asynch} - T_{synch} \quad \text{(I.M.2)} \tag{9}$$

where

$$T_{asynch} = \frac{T_{max}}{\frac{s}{s'_{T_{max}}} + \frac{s'_{T_{max}}}{s}} \cdot (1 + \cos\delta) + \frac{T_{max}}{\frac{s}{s'_{T_{max}}} + \frac{s'_{T_{max}}}{s}} \cdot (1 - \cos\delta) \tag{10}$$

$$T_{synch} = T_{max} \cdot \sin\delta \cdot \left\{ \frac{\frac{s}{s_{T_{max}}}}{\frac{s}{s_{T_{max}}} + \frac{s_{T_{max}}}{s}} - \frac{\frac{s}{s'_{T_{max}}}}{\frac{s}{s'_{T_{max}}} + \frac{s'_{T_{max}}}{s}} \right\} \tag{11}$$

$$s_{T_{max}} = \frac{Rr}{X\sigma} \tag{12}$$

$$s'_{T_{max}} = s_{T_{max}} \frac{Rr + 2Rad}{Rr} \tag{13}$$

The stability range is defined by 0 < δ < 90 °. Motors having the same mechanical loads correspond to δ = 0°. Stability range can be improved by adding higher additional rotor resistance. If mechanical loads differences grow up, the electric shaft can be "broken" and each I.M. will operate independently at different speeds, according to its own speed-load characteristic. At this "broken shaft" operation rotor losses are much increased due to superposition of two different currents and frequencies.

II. PROPOSED "STATIC ELECTRIC SHAFT"

This drive is very similar to the previous one, but it considers the extension to any number of identical induction motors I.M. Instead of a common additional rotor resistance R_{ad}, rotors are connected in parallel across a non controlled rectifier. The rotor active power is feedback to the main AC lines through a controlled 6 pulses bridge inverter (trigger angle $180° > \alpha > 90°$) and transformer. This way, efficiency is very much improved . Fig. 4 shows a diagram for the proposed drive.

Rotors are not directly connected in this proposed drive, hence, rotor frequencies are not forced to be identical, as shown in the Fig. 1 and Fig. 3 for electric shaft under stable conditions. However, DC rectifiers voltages $V_{rect\ n}$ certainly are forced to be identical, because of parallel connection. This voltage depends on I.M. rotor induced voltage and rotor voltage drop. The first one depends on slip, but the second one depends on rotor resistance and rotor leakage reactance. Then, rotor resistance and leakage reactance parameters do affect the speed differences. To describe the proposed drive operation, four operation modes are considered in this paper.

CASE 1: N NO LOADED MOTORS

Under no load conditions, the drive is inherently stable and speed can be determined by the inverter firing angle α. The DC inverter voltage V_{inv} and DC nth rectifier voltage $V_{rect\ n}$ are given by:

$$V_{inv} = 1.35\ V_{sec} \cos\alpha \tag{14}$$

$$V_{Rect\ n} = 2.34\ V_{rn}\ s_n \tag{15}$$

where s_n is the nth induction motor slip and V_{rn} is the rotor induced voltage (per phase) at standstill. V_{sec} is the secondary line-line voltage at the inverter transformer. As in the well known subsynchronous cascade drive at no load [4], both voltages must be equal. The voltage drop in the coil resistance R_d is very small and this way the no load speed of the n rotors can be regulated by inverter firing angle α. Hence, the relationship between shaft speed w_{sh} and firing angle α is given by

$$w_{sh\ n} = (w_r/p_n)(1-(1.35\ V_{sec} \cos\ \alpha)/(2.34 V_{rn})) \tag{16}$$

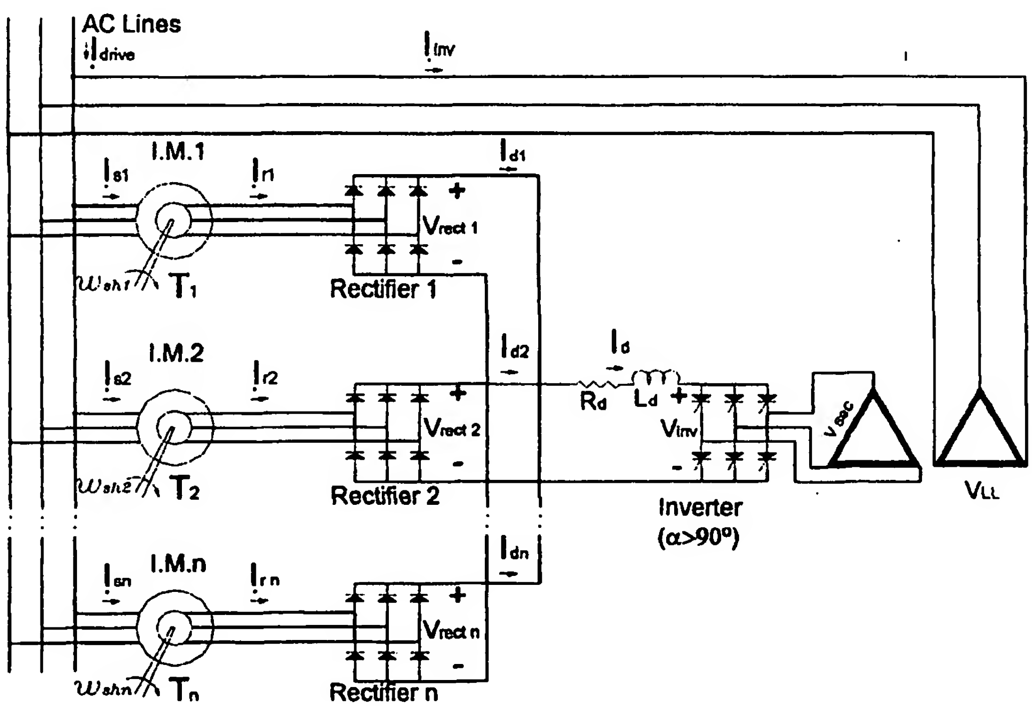

Fig. 4 : Proposed Drive for n Induction Motors

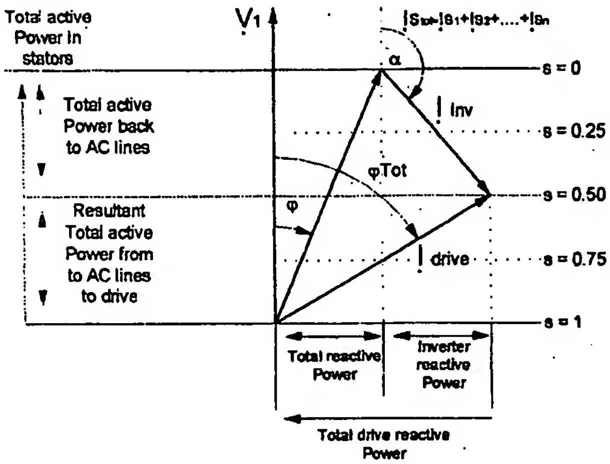

Fig. 5 Approximate Phasor Diagram for n Motors

Fig. 5 shows an approximate phasor diagram for the complete drive. The total active power into the n stators have two components: the active power due to the mechanical loads (friction and windage torque losses in this no load case) and the active power that goes back to the AC lines through the inverter. Concerning the reactive power, it can be supplied by AC lines or by a capacitor bank. In fact, it can be seen that this drive itself has a low power factor. However, efficiency is much better.

If rotor internal resistance losses are small, the fundamental slip rotor power $s P_{ag}$ will be approximately equal to the DC link power [4]. Thus, torque results proportional to DC current I_{dn}. Considering Fig. 4

$$s_n P_{agn} = V_{rect\,n} I_{dn} \quad (17)$$

$$P_{agn} = (T_n w_n)/p_n \quad (18)$$

$$T_n = (V_{rect\,n} I_{dn})/(s_n w_n/p_n) \quad (19)$$

Hence: $$T_n = (1.35 V_L I_{dn})/(a w_n/p_n) \quad (20)$$

Where :

P_{agn} : active power in the nth motor air gap
p_n : number of motor pair of poles
V_L : line to line stator AC voltage
T_n : steady state motor torque for nth I.M.
a : stator / rotor turn ratio
w_n : stator frequency in rad/sec. for nth I.M.

The torque T_n is proportional to the rectified rotor current I_{dn}, which in turn, depends on the difference between the rectified rotor voltage $V_{rect\,n}$ and the average counter e.m.f of the inverter V_{inv}. The smoothing coil L_d has a very small internal resistance R_d.

In order to prove this hypothesis, an experimental test was made at laboratory using five similar rotor winding induction motors 3 kW, 2 poles, 380 line-line V and one inverter, connected as shown in Fig. 4. Next Table 1 to 3 show speeds and electric variables for different inverter firing angles, that is 116°, 132° and 180°.

This Case 1 shows basically the concept of speed variation. The speed of induction motors I.M.1 to I.M.5 can be regulated by changes on firing angle ∝ or by taps in transformer. In this paper the first method was tested. The lowest level speed is obtained for ∝ = 180°, which results in a speed mean value 1.508 rpm +1.0% and -1.8%.

CASE 2: N BALANCED LOADED MOTORS

If motors have approximately balanced mechanical load, rectified currents I_{d1}, I_{d2},... I_{dn} are equals and internal rotor voltage drops should also be equal. Because of parallel connection $V_{rect\,1} = V_{rect\,2} .... = V_{rect\,n}$ and it follows $s_1 V_{r1} = s_2 V_{r2} = ... s_n V_{rn}$. Hence $s_1 = s_2 ... = s_n$ and $w_{sh1} = w_{sh2} = ... w_{shn}$. If motors are different in design, this drive does not work. Under load condition the situation is stable as far as the mechanical loads and motor parameters are similar. Fig. 6 shows phasor diagrams for this condition. The term $R_{rn}(1 - s_n)$ and $R_{rn} s_n$ are associated to the mechanical power and copper losses in the rotor respectively. The rotor leakage reactance in Fig 6c. has been neglected because it is

Table 1. Motors at no load. Inverter Firing angle ∝ = 116°

	W_{shaft} (rpm)	$P_{I.M.}$ (W)	I_S (A)	T (Nt-m)	I_{dc} (A)	V_{dc}(V)
I.M. 1	2.200	270	1.0	0.54	0.8	53
I.M.2	2.200	300	1.0	0.54	0.8	53
I.M.3	2.220	270	0.9	0.2	0.76	53
I.M.4	2.180	360	1.0	0.54	1.2	53
I.M.5	2.180	330	1.3	0.4	1.2	53

Table 2. Motors at no load. Inverter Firing angle ∝ = 132°

	W_{shaft} (rpm)	$P_{I.M.}$ (W)	I_S (A)	T (Nt-m)	I_{dc} (A)	V_{dc}(V)
I.M. 1	1.900	270	1	0.54	0.8	70
I.M.2	1.900	300	1	0.60	0.8	70
I.M.3	1.900	270	0.9	0.30	1.1	70
I.M.4	1.890	360	1	0.54	1.2	70
I.M.5	1.880	330	1.2	0.40	1.2	70

Table 3. Motors at no load. Inverter Firing angle ∝ = 180°

	W_{shaft} (rpm)	$P_{I.M.}$ (W)	I_S (A)	T (Nt-m)	I_{dc} (A)	V_{dc}(V)
I.M. 1	1.520	300	1.0	0.7	1.0	90
I.M.2	1.520	300	1.1	0.6	0.8	90
I.M.3	1.520	270	0.9	0.3	0.7	90
I.M.4	1.500	360	1.0	0.5	1.1	90
I.M.5	1.480	330	1.3	0.4	1.2	90

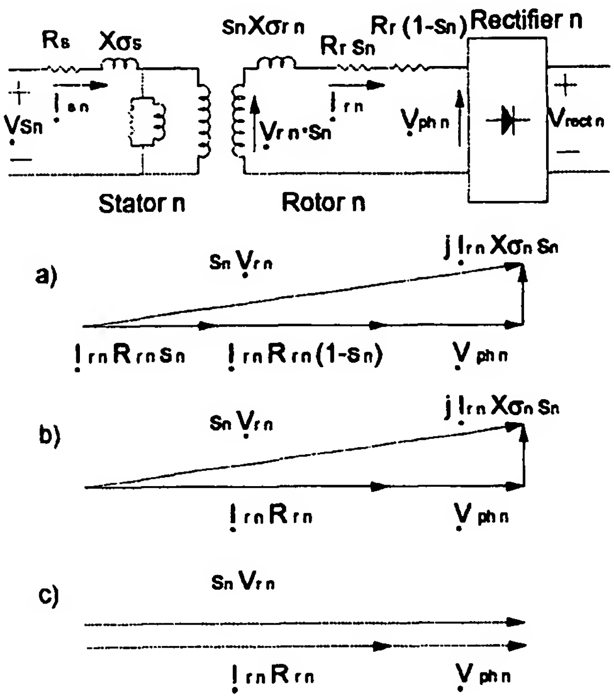

Fig 6 . Phasor diagram for the n[th] loaded motor
(N balanced mechanical load)

proportional to sleep s. Voltage $V_{ph\ n}$ is in phase with fundamental rotor current $I_{r\ n}$ ($V_{rect\ n}\ I_{d\ n}$ correspond to active power regenerated to AC lines trough transformer and inverter). However, a reactive power due to harmonics (the power factor of a 6 diode bridge is 0.94) must be considered. Tables 4 and 5 show speed and electric variables values for the same inverter firing angle and two different mechanical load for each of five similar motors, 3 kW, 380 V.

Results show different speed levels, averaged 1340 rpm +/- 1.5 % in Table 4 and 1035 rpm +/- 3.4 % in Table 5. Under balanced load condition and neglecting leakage reactance voltage drop $I_{rn}\ X_{\sigma n}\ s_n$, the phasor diagram of Fig 6c can be assumed. If motor have similar loads, slip s_n must be equal, so will motor speeds. This hypothesis is valid for identical motor parameters, which happens for same models, series and type as guaranteed by motor factories around the world. Rotor resistance have a strong dependence on temperature.

Table 4. Motors at balanced load. Inverter Firing angle α = 180°

	W_{shaft} (rpm)	$P_{I.M.}$ (W)	I_S (A)	T (Nt-m)	I_{dc} (A)	V_{dc}(V)
I.M. 1	1.340	570	1.3	1.35	2.0	97
I.M.2	1.350	600	1.3	1.35	2.0	97
I.M.3	1.360	540	1.1	1.0	1.8	97
I.M.4	1.320	630	1.3	1.35	2.4	97
I.M.5	1.340	570	1.6	1.0	2.4	97

Total input power: 2.910 w
Total mechanical power 850 w
Total reg.power at rectifier output: 1028 w

Table 5. Motors at balanced load. Inverter Firing angle α = 180°

	W_{shaft} (rpm)	$P_{I.M.}$ (W)	I_S (A)	T (Nt-m)	I_{dc} (A)	V_{dc}(V)
I.M. 1	1.040	990	1.9	2.43	4.0	98
I.M.2	1.050	990	1.9	2.56	4.0	98
I.M.3	1.070	870	1.6	1.90	3.2	98
I.M.4	1.010	1.050	2.0	2.40	4.1	98
I.M.5	1.000	960	2.1	2.16	4.0	98

Total input power: 4.860 w
Total mechanical power 1.240 w
Total reg.power at rectifier output: 1890 w

CASE 3: N UNBALANCED LOADED MOTORS

Due to rectifier output connection, there is no a synchronizing power [1] between machines, as in the case of electric shaft shown in Fig. 3. Stability conditions for this drive are severe and it can be improved by an increase of additional rotor resistance. For three or more motor stability is very difficult. Fig. 7 shows operation and phasor diagram for the "quasi electric shaft", considering two motors. It can be observed that slip differences are due to different rotor voltage drop . Phasor $I_{r1}\ R_r$ is higher than $I_{r2}\ R_r$. That means a higher mechanical torque at I.M.1. Because of $V_{ph\,1} = V_{ph\,2}$, $s_1\ V_{r1}$ must be higher than $s_2\ V_{r2}$. The difference ΔV corresponds to a speed difference given by:

$$w_{sh\,2} - w_{sh\,1} = (\Delta V\, w_1 / V_{r1}\, p_1) \qquad (21)$$

As an example in the next Table 6 speeds and electric variables are shown for different load torque's and for 180° inverter firing angle :

Table 6. Motors at unbalanced load. Inverter angle α = 180°

	W_{shaft} (rpm)	$P_{I.M.}$ (W)	I_S (A)	T (Nt-m)	I_{dc} (A)	V_{dc}(V)
I.M. 1	1.300	330	1.0	0.7	0.9	98
I.M.2	1.230	570	1.3	1.35	2.0	98
I.M.3	1.080	990	2.1	2.2	4.8	98
I.M.4	1.080	1.050	1.9	2.3	4.4	98
I.M.5	1.000	1.290	2.3	3.1	5.6	53

Total input power: 4.23 W
Total mechanical power 1.10 W
Total reg.power at rectifier output: 1.73 W

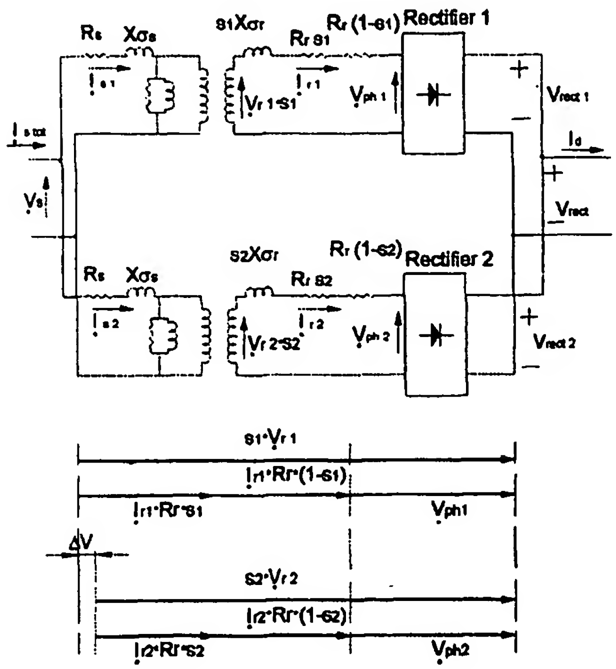

Fig. 7 Approximate Phasor Diagram for Unbalanced Load

It is remarkable that if electric shaft is broken in the drive of Fig. 1 each motor will run independently to its own operating point, according its respective torque-loads characteristic curve. For a similar case in the proposed drive there is a sort of "synchronization" forced trough the subsynchronous cascade .i.e, speed differences are mitigated.

Case 4: Unbalanced Loads And Rotor Resistance Instead Of 6 Pulse Inverter.

In this case speed was adjusted at 1.520 rpm at no load operating point, same as Case 1, Table 3, but using a common rotor resistance R instead of the 6 pulses inverter shown in Fig. 4 Same unbalanced mechanical loads were applied, as in Case 3, Table 6, and it results in a dramatic drop to around 250 rpm. This results are according to the theory: due to diode rectifiers are paralleled, for balanced load it can be considered that each rotor has an additional resistance equivalent to 5 R (at so low speed mechanical loads were very similar). This results show that actually the conventional electric shaft topology of Fig. 3 can not be applied for a significative number of induction motors, five in our case, and it is not possible to expect satisfactory results for practical purposes.

III. Some Comments

Tests at laboratory were made using a 3 kW, 380 V, five "identical" induction motors. Results shown as important influence of motor losses. However, this influence should be reduced as motor rated power is higher. Anyway, the concept of regenerated power is demonstrated. Table 5 shows a total input power 4.9 kW (balanced loads), a regenerated power 1.9 kW and a mechanical power 1.2 kW. Difference is 1.8 kW that corresponds to friction, iron and copper losses of the total five motors. It must be considered that Eq. (17) means a regenerated power equivalent to the so called "slip power" and this is valid for no load operation.

The concept of "electric shaft" means same frequency in stators and same frequency in all rotors. Here this is partially true (stators), but the output paralleled rectifier forces this idea.

Different mechanical loads mean different electric torque and, i.e, different rotor currents. If voltage drop at rotor resistance is not negligible, this difference must be compensated with the value of s V_r, i.e., motor speed. This resistance effect should be mitigated as motor rated power is larger. Also, rotor resistance temperature dependence must be considered

IV. Advantages and Disadvantages of The Proposed Drive

Advantages

COST: If losses are neglected, power regenerated to three phase network is approximately s P_{ag} [4]. So, the power converter is very small in comparison to an stator AC drive (inverter connected to stator, rotor shortcircuited). As an example, suppose that speed varies approximately in a range 100% to 80 % of no load speed and a five induction motors "static shaft" drive is designed. This means it is required one cascade converter (inverter to feedback active power) with a rated power equals to the one motor rated power and five 20% rated power diode bridge. As an alternative, if an static adjustable speed drive (ASD) is used in stator, it is necessary five ASD drives with rated power similar or higher than motor rated power (or one ASD rated five times this power). Fig. 8 shows this idea

MOTORS LOCATION: Motor location is not a boundary condition for this drive. However, it must be kept in mind that voltage drops in rotor AC lines can affect the speed behavior.

DYNAMIC RESPONSE: If one of the motor is loaded with a different torque load, rotor speed compensation across the DC voltage works simultaneously for all the motors.

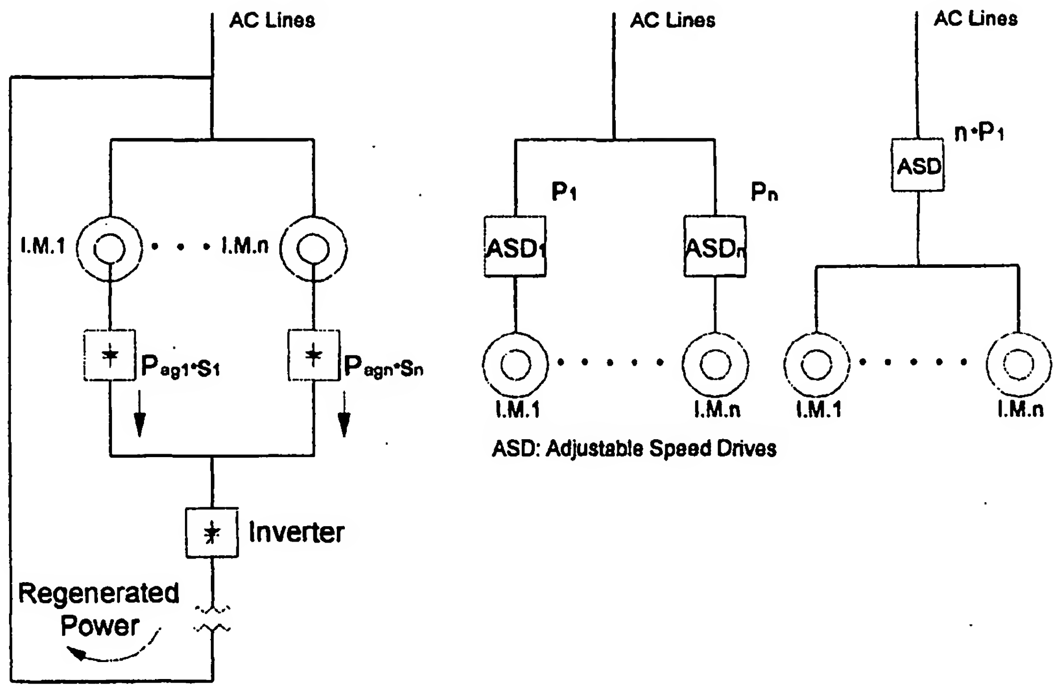

Fig. 8 Drive Alternatives

NUMBER OF MOTORS : Conventional electric shaft use to be designed for only two motors. For the case of 3 or more induction machines very complicated stability problems take place and very small speed stability range is obtained. The proposed "static electric shaft" can be used for any number of motors.

SPEED LEVEL: The speed is defined by the most loaded motor.

EFFICIENCY: In conventional electric shaft additional rotor resistance are used to stabilize the operating point. That means extra losses . In the proposed drive, the differences between input stator active power and mechanical power are back to the AC lines trough the subsynchronous cascade.

SIMPLICITY: This is a very simple drive in comparison with more complete alternatives [5].

DISADVANTAGES

INDUCTION MOTOR PARAMETERS: This means that motor parameters affect strongly the drive behavior [6] and in this case must be as identical as possible (stator and rotor resistance, stator and rotor leakage reactance's, magnetizing reactance's, friction losses, windage losses, etc) This is mitigated, considering the design quality criteria of the most important machinery factories around the world.

SPEED RANGE: Even though subsynchronous cascade can be designed to have a very large subsynchronous speed range, heating problems could take places for small speed (or high rotor slip). From this point of view it is recommended a speed range no further than 40 % down from synchronous speed. Any way, this range is very attractive for a lot of drives.

SPEED EXACTITUD Conventional electric shaft under stable operation condition assure exactly the same speed, because rotor frequency are identical for each motor (stator frequencies are identical). In the case of "static electric shaft" this speed condition is indirectly imposed by the same voltage condition in the output of rectifier : same DC voltage = same rotor slip if secondary voltages are equals . This conclusions are valid at no load condition or at the same mechanical load for all motors. However, subsynchronous cascade and rectifier connected in parallel tends to balance rotor currents and rotor voltage drops.

REACTIVE POWER Eventhough active power is regenerated to the AC network, it must supply reactive power that depends on the controlled inverter trigger angle. In addition, AC network must supply the reactive power to sustain the magnetic rotary field of the induction machine

itself. So, total drive power factor must be improved by the use of a capacitor bank. Reactive power can be mitigated by a transformer with several taps between AC lines and inverter. Transformer have a very important advantage here : it is possible to adjust firing angle and make it closer to 180° for an specific operating point. (that means to get an inverter high power factor).

V. Conclusions

A very simple and cheap solution for variable speed drive formed by n rotor winding induction motors that must operate at approximately the same speed has been presented. Concerning the conventional electric shaft, this drive have a very high efficiency because it involves active power regenerated to AC main lines at full operating range. The motor speeds are very similar for no load and balanced individual mechanical loads. However, for unbalanced mechanical loads, the differences in speeds are not remarkable and are mitigated by the subsynchronous cascade. This drive can be an appropriate solution for those drives that require a great deal of variable speed "synchronized" motors and speeds are not required to be strictly identical.

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